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## (54) Liquid Metal Switch

(57) A high-current liquid metal switch in which one contact 2×8 is entirely fixed and is in the form of an upper plate 2 while the other contact has a fixed part 1 in the form of a similar plate but having a cylindrical hole containing a movable contact member 18 immersed in a liquid metal. The contact member 18 is sealed to the surrounding fixed part 1 by means of a flexible bellows 13 which contains the liquid metal and allows the contact member 18 to be driven upwards carrying the liquid metal with it. Contact is first made between the liquid metal and the upper fixed contact 8 and then the movable contact member 18 continues upwards through the liquid metal to make solid contact. The contact construction is of a very simple sandwich form, the liquid metal and a ceramic spacer 3 being sandwiched between the contact part 1 and plate 2.

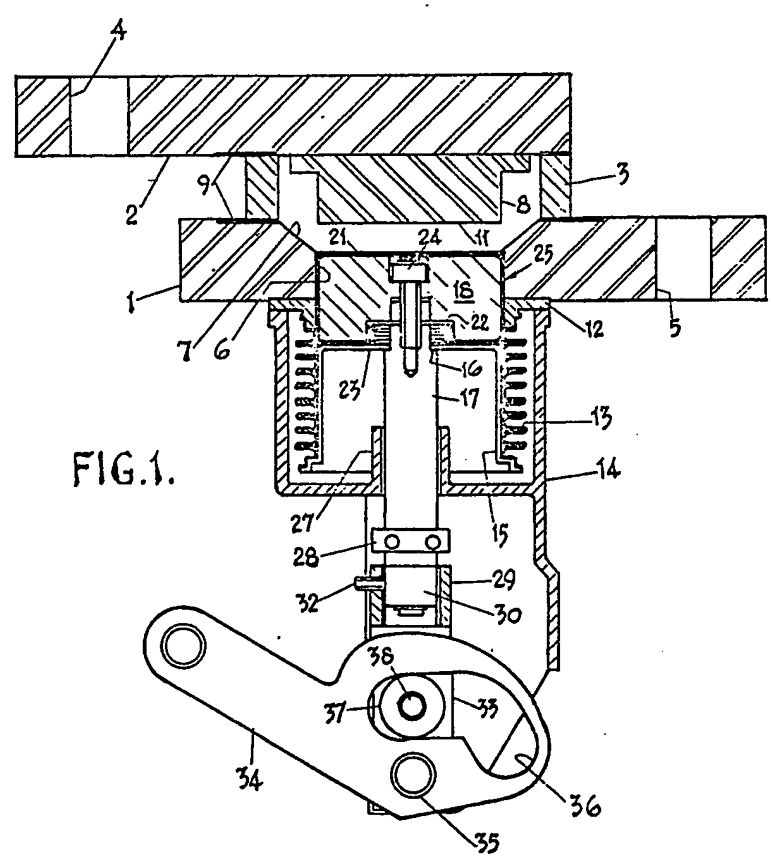


FIG.1.

SWITCH OPEN

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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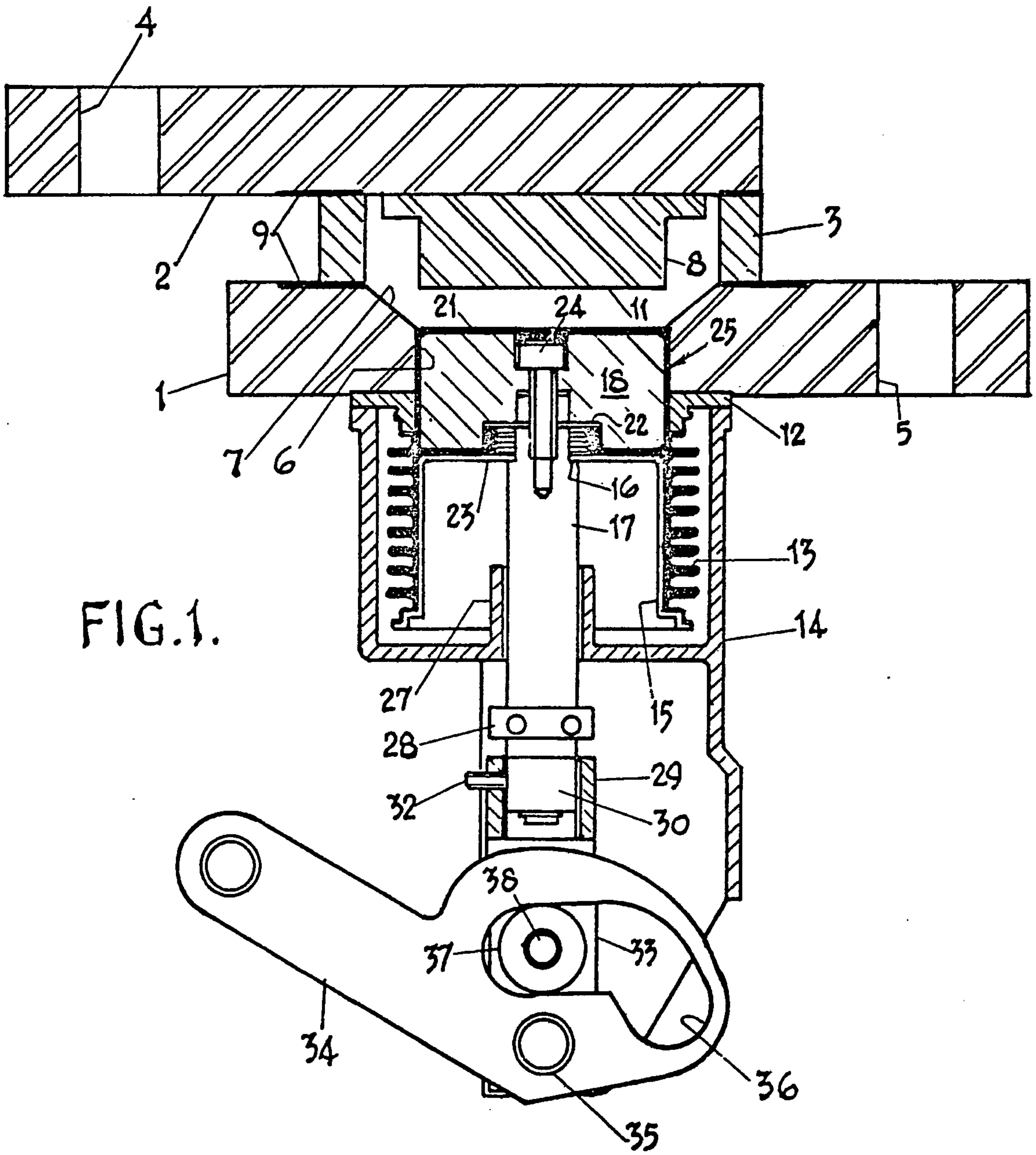
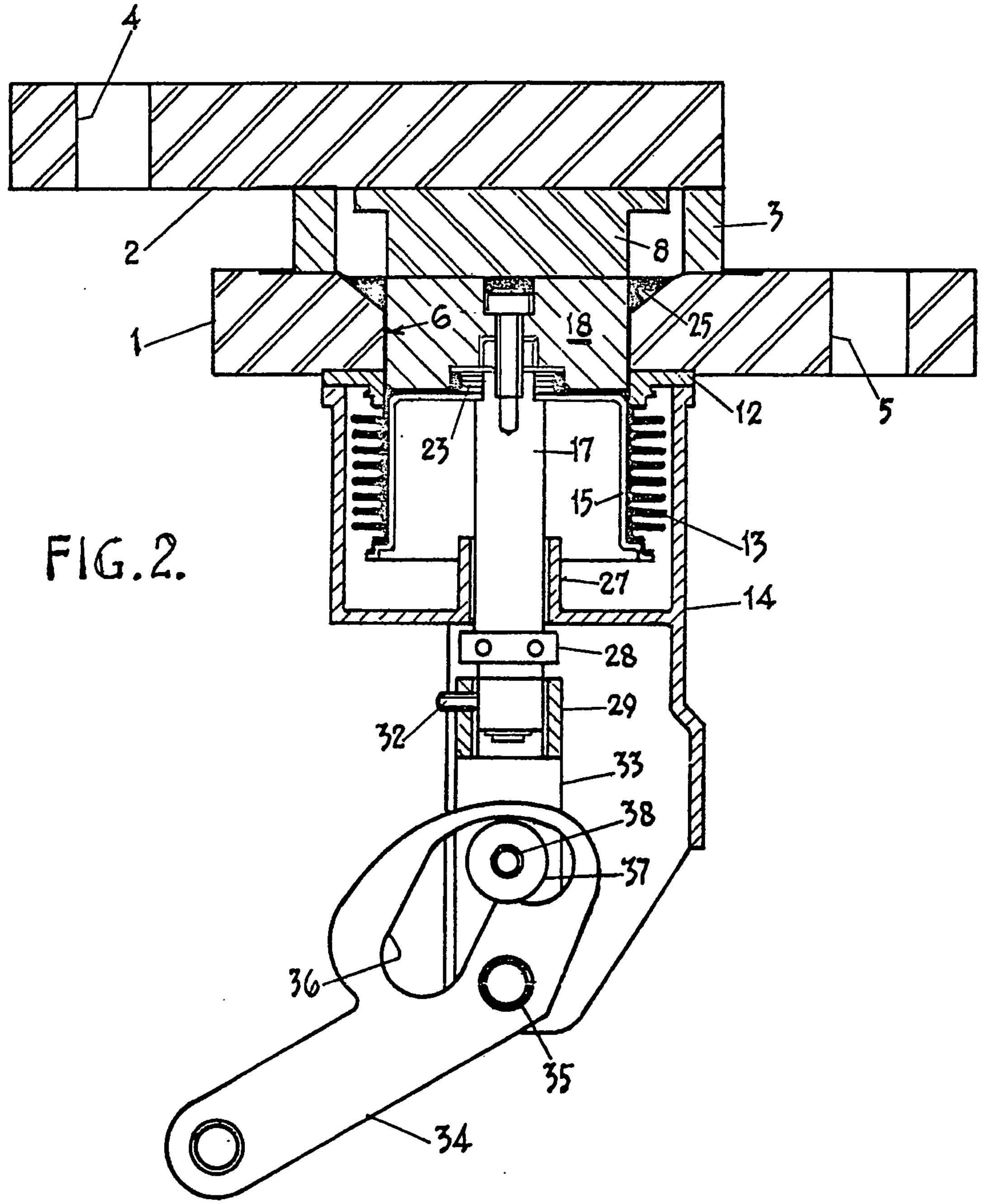



FIG.1.

SWITCH OPEN

FIG.2.




SWITCH CLOSED

SPECIFICATION
**High-Current Liquid-Metal Switch**

This invention relates to high-current liquid-metal switches and particularly to such switches which operate at potential differences between the switch terminals of low values, typically five volts. It is also particularly, but not exclusively, concerned with direct current switches.

One difficulty in the design of such switches is the problem of stabilizing the liquid metal while it is carrying very large currents, of the order of tens of thousands of amps perhaps. A further disadvantage of previously proposed switches of this kind is their complex construction which increases the cost of production considerably.

It is therefore an object of the present invention to provide a high-current liquid metal switch of basically simple construction.

Accordingly, therefore, a high-current electrical switch comprises first and second spaced-apart fixed contact members forming part of a sealed enclosure and between which a current path is established on closure of the switch, a mass of liquid metal, and a movable conductor member arranged to move between said contact members to fill at least part of the gap between them on closure of the switch, said movable conductor member also being effective to displace said liquid metal into contact with said second fixed contact member to close said current path, the contact surface of said second fixed contact member being of planar form and parallel to the contacting surface of the liquid metal.

The first contact member is preferably of planar form mounted parallel to said contact surface and has a cylindrical aperture within which said conductor member is mounted to move axially. The conductor member is preferably separated from the wall of the aperture by a layer of the liquid metal.

The sealed enclosure preferably includes an elastic bellows sealed around the aperture in the first contact member, the conductor member being mounted in fixed relation to another part of the bellows to permit operation of the switch from outside the sealed enclosure. The liquid metal is preferably contained by the bellows so that closing movement of the conductor member with accompanying compression of the bellows causes the liquid metal to rise relative to the conductor member, the cross-section of the sealed enclosure in planes parallel to said contact surface increasing with the level of the liquid metal so that prior to switch closure the depth of immersion of the conductor member varies to a lesser extent than it would with a constant cross-section. The increase in cross-section may be provided by a conical upper portion of the aperture. The bellows is preferably of cylindrical form and closed off at said other part by a closure member which is of cylindrical form and occupies most of the space within the bellows, the liquid metal being contained between the first contact member, the bellows and the closure member.

The closure member is preferably mounted on and sealed to a driving member which is movable axially with respect to the aperture, the conductor member being mounted on the driving member so as to lie entirely within the sealed enclosure.

The conductor member is preferably movable into solid contact with the second contact member after the current path is established by the liquid metal.

The conducoor member is preferably resiliently mounted on the driving member to provide spring-loaded contact between the conductor member and the second contact member in the switch-closed condition.

The closure member is preferably hollow and the driving member a shaft lying within the closure member and outside the sealed enclosure, an axial bearing, fixed in relation to the contact members, being provided for the shaft.

The first contact member preferably extends transversely away from the aperture with approximately constant cross-section to form a terminal connection for the switch.

The second contact member may comprise a portion of planar form with which is incorporated a contact element projecting towards the first contact member and providing said contact surface. The planar portion of the second contact member preferably extends in a direction parallel to its planar form with approximately constant cross-section to form a terminal connection for the switch. The contact element may have a contacting surface which lies approximately in the mouth of the aperture in the first contact member.

A high-current liquid-metal switch will now be described, by way of example, with reference to the accompanying drawings, of which:

Figure 1 is a sectional view of the switch in an open condition; and

Figure 2 is a sectional view of the switch in a closed condition.

Referring to Figure 1, the switch comprises first and second contact members 1 and 2 of copper which sandwich between them a ceramic annulus 3. The annulus 3 is sealed to the contact members 1 and 2 by means of copper gaskets 9 having a concentric rib formation and bolts, not shown, which clamp the 'sandwich' together. The contact members 1 and 2 are in the form of thick rectangular plates shown sectioned on their shorter dimensions. In addition to forming contact members they also provide terminal connections to the switch, a series of holes 4 and 5 along one long edge of each being provided for fixing to bus-bars.

The first contact member 1 has a cylindrical aperture 6 formed in it coaxial with the ceramic annulus 3. The upper part of the aperture is formed with a conical portion 7, for a purpose to be explained.

The second contact member 2 is of similar form to that of the member 1 but without an aperture 6. It is, however, fitted with a contact element 8, a disc of copper of thickness conveniently equal to the gap between the

contact members so that the contact surface 11 of the disc is approximately in the plane of the mouth of the aperture 6. This is not, however, a critical requirement. The diameter of the disc approximates to that of the aperture 6.

Fixed to the underside of the contact member 1 is a collar 12 having a bore continuous with the aperture 6. At the inner part of this collar one end of a flexible bellows 13 is welded while at the outer edge a metallic housing 14 is fixed. Both collar 12 and housing 14 are held clamped to the contact member 1 by the main clamping bolts (not shown) and a retaining ring. In this example the lower end of the bellows 13 is closed off by a closure member 15 in the form of an inverted cylindrical can which occupies most of the space within the bellows. This closure member 15 has a central hole which sits on and is sealed to, a shoulder 16 of a driving shaft 17. A sealed enclosure is thus provided by the contact members 1 and 2, the ceramic annulus 3, the bellows 13 and the closure member 15.

Also mounted on the driving shaft 17, and within the sealed enclosure, is a conductor member 18, being a solid copper cylinder with a flat, upper, contact surface 21 parallel to the general planes of the contact members 1 and 2. This conductor member 18 is mounted on the driving shaft 17 by way of a plain washer 22 and a pile of Belleville washers 23 to provide a spring mounting. The conductor member is then clamped down by a counterbored screw 24 leaving some room for further compression of the spring washers.

The conductor member 18 is a loose fit in the aperture 6. The space contained by the wall of the aperture 6, the conductor member 18, the bellows 13, and the closure member 15 is filled with a liquid metal 25 of which gallium is at least a constituent and which is preferably an alloy of gallium and indium or gallium, indium and tin. The remaining space of the sealed enclosure contains an inert gas such as argon, helium etc. to inhibit any oxidation of the liquid metal under the arcing conditions which occur in operation.

The mass of liquid metal is such that in the open condition of the switch, i.e. as shown in Figure 1, the level of the liquid metal is just above the surface of the conductor member 18. This level is not, of course, critical but it does keep the contact surface of the conductor member 18 wetted in the open switch condition.

It may be seen from the drawing that the mass of liquid metal is of small bulk and consists in fact of a number of narrow layers, between the conductor member 18 and the contact member 1, between the bellows 13 and the closure member 15, and between the conductor member 18 and the top of the closure member 15. This design of the liquid metal passageways avoids a large bulk of liquid metal which would be difficult to keep stable under high-current conditions.

The drive shaft 17 extends downwards axially within the closure member 15 and through a tubular part 27 of the housing 14 which acts as a bearing or guide for the shaft. This bearing 27 can lie almost entirely within the closure member 15 and thus conserve space in the axial direction.

At its lower end, the shaft 17 is stepped down in diameter and carries on the reduced portion an externally threaded collar 30 having a head 28 for manual rotation, the collar being free to rotate on the shaft 17 but trapped axially by a circlip. The threaded collar 30 engages an internally threaded drive post 29, the depth of insertion of the collar in the post being adjustable by rotation of the collar. Having set the depth of the collar, a screw 32 locks the collar against rotation.

The drive post 29 is forked at its lower end in two planes at right angles. The longer forks, of which one, 33, is shown, carry a cam follower 37 on a pin 38. The other fork, of shorter extent, sits astride a pin 35 which is mounted in an extension of the housing 14 and on which is pivoted an operating lever 34. This operating lever has a slot 36 providing a desmodromic cam surface for the follower 37. Rotation of the operating lever through the angle shown is effected by a solenoid motor, not shown, by pneumatic cylinder, directly by manual operation, or by other convenient means.

In the switch-open condition the bellows are in a relaxed condition dependent upon the position of the collar 30 as previously explained. Since the cam surface is at right angles to the shaft motion at this point the position is stable and the switch is effectively latched open. As the lever 34 is rotated anticlockwise, to the position shown in Figure 2, the roller 37 is driven upwards, together with the drive post 29 and the shaft 17, so compressing the bellows and driving the conductor member 18 upwards.

As the bellows contracts, the liquid metal is squeezed upwards into the conical portion of the aperture 6, all the time maintaining its level just above the contacting surface of the conductor member 18. As the bellows is compressed the contained volume of liquid metal decreases so that the level of the liquid metal tends to rise faster than the level of the contact surface of the conductor member 18. The result would be that the depth of immersion of the conductor member at the point where the liquid metal made and broke contact with the contact element 8 would be unnecessarily great, with resulting excessive turbulence and instability of the liquid metal in the arc gap.

In accordance with a feature of the invention the sealed enclosure has a cross-section which increases as the liquid metal surface rises, to accommodate the increased quantity of the liquid metal. In particular the upper portion of the cylindrical aperture 6 is of conical form, diverging upwardly. The layer of liquid metal on top of the conductor member 18 is thus maintained at an approximately constant and fairly small depth.

The initial closure of the current path between the two contact members is effected between the lower surface 11 of the contact element 8 and the upper surface of the layer of liquid metal, both of

these surfaces being of substantial area and parallel to the general planes of the contact members.

As the upward drive of the shaft continues, the conductor member 18, which, or course, has been continually in electrical contact with the first contact member 1, moves through the intervening liquid metal connection and makes solid contact with the contact element 8. Being immersed in liquid metal, this engagement produces no arcing and consequent damage to the solid contact surfaces.

The spring loading of the conductor member 18 takes up any inaccuracies in manufacture that there may be and allows the upper surface of the conductor member to align itself with, and bed down onto, the contact element 8. The further compression of the Belleville washers 23 when the conductor member 18 makes solid contact is determined by the uppermost position of the shaft 17, which is set by adjustment of the collar 30. The resulting spring contact pressure is set at a level sufficient to withstand the electromagnetic blow-off forces which arise under heavy current conditions.

There are then parallel current paths from the contact member 1 to the contact member 2, a major path through the conductor member 18 and intervening liquid metal, and a minor path through the annular portion of the liquid metal direct to the contact element 8.

The closed condition of the switch, as shown in Figure 2, is also a latched condition since the profile of the cam underneath the follower 37 is again at right angles to the path of movement of the follower and drive post 29.

To open the switch the lever 34 is rotated clockwise and the roller 37 pulls the drive post and conductor member 18 down as it follows the cam profile. As conductor member 18 separates from contact element 8 the gap between them is filled with liquid metal. Current continues to flow through the switch until the gap between conductor member 18 and contact element 8 is sufficiently large to allow the electromagnetic forces due to the current to squeeze the liquid metal in the gap into a thin neck which is then heated by the passage of current until it explosively disrupts and initiates an arc. In this way both ends of the arc are made to run on liquid metal, and the solid members 8 and 18 are protected from damage. Liquid metal which is evaporated by the arc recondenses to the liquid phase and can therefore be reused.

The contact surfaces of the contact element 8 and/or the conductor member 18 may be coated with tungsten or molybdenum for additional protection against arcing during the current breaking operation.

It may be seen that the invention provides a main contact construction which is extremely simple compared to previously proposed arrangements. Each contact member may be formed continuously with the associated terminal connection, the two contact members being essentially plates sandwiching the contact gap.

In addition to providing a low resistance sliding joint (between contact member 1 and conductor member 18) and a main contact surface, the same liquid metal can be used to advantage between the contact element 8 and the contact member 2 which are bolted together. The contact resistance is thereby greatly reduced.

In a modification of the switch described, a combination of bellows and a diaphragm may be used to mount the conductor member, the diaphragm providing movement without the accompanying pumping action that results from use of the bellows described.

## Claims

1. A high-current electrical switch comprising first and second spaced-apart fixed contact members forming part of a sealed enclosure and between which a current path is established on closure of the switch, a mass of liquid metal, and a movable conductor member arranged to move between said contact members to fill at least part of the gap between them on closure of the switch and to displace said liquid metal to effect the closure of said current path by liquid metal, wherein the initially contacting surfaces are of planar form, arranged to be parallel in operation.

2. A high-current switch according to Claim 1, wherein the first contact member is of planar form mounted parallel to said contacting surfaces and has a cylindrical aperture within which said conductor member is mounted to move axially.

3. A high-current switch according to Claim 2, wherein said conductor member is separated from the wall of said aperture by a layer of said liquid metal.

4. A high-current switch according to Claim 2 or Claim 3 wherein said sealed enclosure includes an elastic bellows sealed around said aperture in the first contact member, said conductor member being mounted in fixed relation to another part of the bellows to permit operation of the switch from outside the sealed enclosure.

5. A high-current switch according to Claim 4, wherein the liquid metal is contained by the bellows so that closing movement of said conductor member with accompanying compression of the bellows causes the liquid metal to rise relative to the conductor member, and wherein the cross-section of the sealed enclosure in planes parallel to said contact surface increases with the level of the liquid metal so that prior to switch closure the depth of immersion of the conductor member varies to a lesser extent than it would with a constant cross-section.

6. A high-current switch according to Claim 5, wherein said increase in cross-section is provided by a conical upper portion of said aperture.

7. A highcurrent switch according to any of Claims 4, 5 and 6, wherein said bellows is of cylindrical form and is closed off at said other part by a closure member which is of cylindrical form and occupies most of the space within the

bellows, the liquid metal being contained between the first contact member, the bellows and said closure member.

8. A high-current switch according to Claim 5, 6 or 7, wherein said closure member is mounted on and sealed to a driving member which is movable axially with respect to said aperture, said conductor member being mounted on said driving member so as to lie entirely within said sealed enclosure.

9. A high-current switch according to any preceding claim, wherein said conductor member is movable into solid contact with said second contact member after said current path is established by said liquid metal.

10. A high-current switch according to Claim 8, wherein said conductor member is resiliently mounted on said driving member to provide spring-loaded contact between said conductor and said second contact member in the switch closed condition.

11. A high-current switch according to any of Claims 8, 9 and 10, wherein said closure member is hollow and said driving member is a shaft lying within the closure member and outside the sealed enclosure, an axial bearing, fixed in relation to the contact members, being provided for the shaft.

12. A high-current switch according to any of Claims 2 to 11, wherein said first contact member extends transversely away from said aperture with approximately constant cross-section to form a terminal connection for the switch.

13. A high-current switch according to any preceding claim, wherein said second contact member comprises a portion of planar form with which is incorporated a contact element projecting towards the first contact member and providing said contact surface.

14. A high-current switch according to Claim 13, wherein the planar portion of said second contact member extends in a direction parallel to its planar form with approximately constant cross-section to form a terminal connection for the switch.

15. A high-current switch according to Claim 13 or Claim 14 as appendent to Claim 2, wherein said contact element has a contact surface which lies approximately in the mouth of the aperture in the first contact member.

16. A high-current switch substantially as hereinbefore described with reference to Figures 1 and 2 of the accompanying drawings.

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